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prepared for members of the Solar Physics panel of NASA.

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It is not intended as a final report for release to other interested parties. Your comments are invited.

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I. OUTLINE OF THIS STUDY

A scientifically instrumented space vehicle capable of approaching significantly closer to the sun than orbiting Earth satellites appears feasible from a technological point of view at the present time. The rapid growth of the space sciences and the construction of larger and larger booster rockets lends promise that both the feasibility and desirabiligy of such vehicles will evolve considerably in the next few years. For these reasons, it seems useful to think seriously about desirable experiments that possibly might be carried out aboard such a space craft. We have initiated, with support from NASA, Ames Research Center, such a study with particular emphasis on experiments relative to electromagnetic radiation from the sun and the nature of the interplanetary medium. We have not considered in detail the many interesting experiments relative to particles and fields measurements near the sun. This choice was made with the understanding that other groups were considering the particles and fields experiments and does not reflect either lack of interest on our part or a feeling that these experiments are less useful. Indeed, it seems immediately evident that many of the more interesting experiments aboard such a space craft will involve particles and fields measurements.

This report is the outgrowth of informal discussions along the lines mentioned above with various scientists in the Boulder, Colorado community interested in solar, interplanetary and terrestrial atmospheric phenomena. Some of the discussions were of a seminar type with strong audience participation and others were private. We have not attempted to label all ideas expressed nor criticisms of ideas with the names of particular individuals. Thus, this report has been influenced by many people, even though, in most cases, they are unnamed. The responsibility for accurate reporting, however, lies solely with the authors.

The nature of our discussions can be summarized by the following questions which are indicative of our general approach to the subject: (1) What experiments would be useful to carry out from a space vehicle approaching the sun from Earth? (2) What is the specific scientific purpose of these experiments? (3) At what maximum distance from the sun do these experiments offer enough improvement over similar experiments carried aboard orbiting Earth Satellites to justify the added technical difficulties of approaching near to the sun? (4) What are the general requirements of the space craft for pointing accuracy and control?

The first question led to a rather uncritical listing of experiments, some of which could be immediately discarded when challenged by questions (2) and (3). We have retained some of these easily discarded experiments in this report for the sake of completeness and future reference. In doing so, we do not wish to imply that our list is complete in any sense. The list represents simply those experiments that were of interest to some member of the discussion group. The second question asks essentially for a scientific justification of a proposed experiment in order to distinguish the meritorious experiments from those that are suggested simply because they become possible under the particular circumstances. The third question is difficult to answer in many cases and involves some knowledge of the technical difficulties of performing such experiments. We have considered these difficulties only in crude terms, and because of this limitation we have set the maximum distances in equally crude terms. The fourth question is similarly involved in technology. We have included it because it is relatively easy to answer without knowing details of instrument design, etc., and because it is helpful in the planning of a solar probe vehicle. We have specifically avoided detailed considerations of weight, power and telemetry requirements.

The discussion that follows is not intended in any way as a proposal for support of specific space experiments. It is intended only as a guide to those who subsequently may wish to propose experiments.

II. General Considerations

The scientists' wish to observe the sun and its space environment from vantage points nearer to the sun than the orbit of Earth is prompted by a desire to gain better physical understanding of the sun and its environment. An observing station nearer the sun would experience a greater density of radiant flux from the sun and would view a sun of large angular diameter. As a result, small features on the sun and faint emissions would be relatively easier to detect. Furthermore, the nature of solar phenomena is such that we cannot safely assume that an observer at Earth is capable of detecting all that transpires on or near the sun. In particular, magnetic field configurations near the sun may change markedly with little or no detectable change at the orbit of Earth; and clouds of solar plasma may be ejected from the sun in association with many flares, or other solar phenomena, without ever producing an observed effect at the orbit of Earth. Finally, an observer at Earth can acquire only very restricted observations of such phenomena as zodiacal light, the F-corona and the solar wind. Observations at closer approaches to the sun offer hope for great improvements in the quality and quantity of data available for the study of such phenomena.

The sun is an extended source rather than a point source, and the advantages to be gained by a close approach must be carefully considered. A given focussing lens will intercept radiant flux in proportion to r^{-2}, where r is the distance from the lens to the sun. The image formed, however, increases in area in proportion to r^{-2} with the result that the surface intensity in the image is constant. Thus, a spectrograph, for example, with a given imaging system and a fixed slit that is smaller than the solar image will not experience any increase in the flux passing through the slit as r is changed. The ratio of image area to slit area, however, will increase in proportion to r^{-2}, and the spectrograph will gain in spatial resolution of the solar image. On the other hand, if the gain in spatial resolution is sacrificed by enlarging the entrance slit of the spectrograph the flux received will increase in proportion to r^{-2}.

Linear resolution on the sun increases in proportion to r^{-1} as r is decreased. At a fixed distance from the sun, the theoretical linear resolution is proportional to the diameter of the objective flux collector. Thus, an approach to 0.1 A.U. is equivalent to increasing the diameter of the flux collector at 1 A.U. by a factor of 10, which results in an increase in flux collecting power by a factor of 10^2.

We have arbitrarily adopted this increase as the marginal value for studies aimed at increased spatial resolution, i.e., the increased angular resolution becomes a compelling factor when $r \leq 0.1$ A.U.

Since the total flux received by a collector increases in proportion to r^{-2}, a theoretical increase in useful flux of a factor 10^2 is achieved at 0.1 A.U. In many cases, however, this total increase can not be utilized because of design problems. Again, we have set 0.1 A.U. as the general marginal condition for studies requiring greater flux levels. Some notable exceptions to this arbitrary condition will arise, however.

In setting the above limits, we recognize that it is technologically far more difficult to reach 0.1 A.U. than to reach 0.3 A.U., and that this alone may offset the advantages gained by shorter distance from the sun. We have not taken this into consideration. Instead, we have proceeded under the assumption that the difficulty of achieving a major reduction in r is roughly comparable to increasing either flux collecting power or the sensitivity of flux detection by a factor of 10^2. A solar proble at 0.3 A.U. would very definitely present strong advantages in increased spatial resolution on the sun and minimum observable intensities. However, it seems to us to be more realistic to attempt to achieve this same gain by increasing the flux gathering power of instruments aboard Earth satellites by a factor of 10.

A further advantage of a close solar probe over an Earth satellite is in the required accuracy and stability of pointing. For example, a solar feature such as a spicule or granule with 1" of arc angular size at the orbit of Earth subtends 3.3" of arc at 0.3 A.U. and 10" of arc at 0.1 A.U.

The pointing accuracy and stability of the space vehicle required to observe such features is therefore substantially less than at 1 A.U. Again, the relative expense of this gain must be weighed in terms of the engineering difficulties, which we do not feel competent to judge. For this reason, we have excluded from our study any consideration of experiments designed primarily for achieving very high spatial resolution. We have included some experiments where merely "better" resolution is desired, however.

III. SUMMARY OF SUGGESTED EXPERIMENTS

A. - Lyman-α; Interplanetary Absorption. (Suggested by Warwick and Todd)

The purpose of this experiment is to determine the distribution of neutral hydrogen in interplanetary space by searching for a narrow absorption feature in the solar spectrum near Lyman-α. For a stationary hydrogen gas, the absorption core in Lyman-α would have a doppler width of about .04 to .13 Angstroms, corresponding to assumed temperatures of 10^4 and 10^5 °K, respectively. The depth of the absorption feature will depend upon the number of neutral hydrogen atoms between the probe and the sun. A depression by about 0.1 would occur if there were 3×10^{12} neutral hydrogen atoms in the optical path from probe to sun. At a probe distance of 1 A.U. this would correspond to an average neutral hydrogen density in interplanetary space of about .2 per cm^3. (The absorption coefficient at line center for Lyman-α is 0.56×10^{-13} for a temperature of 10^4 °K and 0.19×10^{-13} for a temperature of 10^5 °K.)

This experiment would involve crude pointing towards the sun and a spectral resolution of about .1A. This would not give an accurate profile for the absorption component, but would be sufficient to give the total absorption. A resolution of 0.01 is required for studies of the absorption profile, which would provide valuable new data.

If the interplanetary neutral hydrogen is moving outwards from the sun with an average radial velocity of, say, 500 km/sec, the absorption line would be shifted 1 Angstroms to the violet of the normal Lyman-α line, and could be difficult to observe as an absorption line. This point, together with comments on the possible origins of interplanetary neutral hydrogen are discussed in a subsequent section.

Measurements of the total absorption in the core of the direct solar Lyman-α line appear to be possible and would provide valuable data on interplanetary hydrogen. If possible, enough spectral resolution to obtain accurate profiles of the absorption core should be utilized.

The data would be of interest over the entire flight path. The probe should approach within 0.5 A.U. of the sun.

B - Lyman-α; Interplanetary scattering. (Suggested by Athay)

The purpose, again, is to determine the distribution of neutral hydrogen in interplanetary space by searching for Lyman-α emission produced by scattering from neutral hydrogen atoms.

If we assume, for convenience, that neutral hydrogen is uniformly distributed in interplanetary space, the Lyman-α photon flux arising at a 90° angle to the sun-probe line is (see appendix)

$$8.3 \times 10^{9} N_H R/r, \text{ cm}^{-2} \text{ sec}^{-1}, \tag{1}$$

and the flux arising from a point opposite the sun

$$5.3 \times 10^{9} N_H R/r, \text{ cm}^{-2} \text{ sec}^{-1}, \tag{2}$$

where N_H is the number of scattering atoms in a cubic centimeter r is the probe-sun distance and R is the Earth-sun distance. A Lyman-α photon counter capable of detecting 1×10^{9} photons per sec, would therefore be able to detect at 1 A.U. an average $N_H \geq .12$ looking at 90° to the sun-probe line and an average $N_H \geq .2$ looking directly away from the sun.

If N_H is proportional to r^{1}, the numerical coefficients in equations (1) and (2) are reduced by factors of about 2 and 4, respectively, and N_H is redefined as the ambient N_H in the vicinity of the probe (see appendix). Obviously, N_H cannot continue to increase towards the sun and the approximation that $N_H \propto r^{-1}$ is intended only in the vicinity of the probe and at greater distances from the sun.

If there is enough neutral hydrogen in interplanetary space to be observed in this way, changes in the emission with orientation of the instrument and with distance from the sun should provide the necessary data to determine concentrations and gradients of the neutral hydrogen. The observations need only record the total flux in Lyman-α and preferably should scan across the plane of the ecliptic.

Measurements of Lyman-α emission scattered by interplanetary neutral hydrogen appear to be somewhat simpler to carry out than measurements of the central absorption core in direct solar Lyman-α radiation and would provide essentially the same data. Again, studies of line profiles would substantially increase the value of the data. The profiles of the scattered Lyman-α line would be essentially the same as the profile of the central absorption core.

The probe should approach within 0.5 A.U. of the sun.

C - Lyman-α; Coronal Electron Scattering. (Suggested by Öhman)

Electrons in the solar corona will scatter the chromospheric Lyman-α line, and, because of the high velocity of the electrons, the line profile of the scattered light will be considerably broader than in the normal solar spectrum. The purpose of this experiment is to provide a unique and accurate measure of the coronal electron temperature by measuring the profile of the scattered Lyman-α line. The mean Doppler velocity of coronal electrons (assuming 1×10^6 °K) is 5500 km/sec, which produces a Doppler width in the profile of the scattered Lyman-α line of 22 Angstroms. A spectrograph with 1 Angstrom resolution would give a sufficiently accurate profile.

The flux of Lyman-α photons at the orbit of Earth due to coronal scattering is 1.4×10^6 cm^{-2} sec^{-1}. In order to obtain profile information, this flux must be divided into about 10 bands, leaving an average flux of 1.4×10^5 cm^{-2} sec^{-1} at the orbit of Earth.

The coronal flux is much less than the expected total flux due to interplanetary scattering. However, if the corona is imaged on a photon counter the counter can be shielded from all interplanetary flux except that arising in the solid angle subtended by the corona. This latter flux is comparable to the coronal flux if the probe is at 1 A.U. and $N_H \approx 0.1$. If the probe is at 0.3 A.U., presumably the interplanetary flux decreases markedly and the coronal flux increases by a factor of about 10. At 0.1 A.U. the coronal flux increases by a factor of 10^2 compared to the flux at 1 A.U. and the interplanetary flux decreases still further. Since the profile of the coronal scattered Lyman-α is about 22A wide whereas the profile of the interplanetary scattered Lyman-α is about 0.1A wide, the two components could be separated with rather crude spectroscopic resolution.

This would be a valuable experiment to carry out. The advantage of a close approach to the sun, however, must be weighed in terms of instrumental capabilities and will depend somewhat upon the distribution and density of interplanetary neutral hydrogen.

D - Separation of F and K Corona. (Suggested by Athay)

The true solar corona (K-corona) at sunspot maximum or near the solar equator at sunspot minimum merges at about one radius above the solar limb with a false F-corona produced by forward scattering by interplanetary dust. It is likely that the interplanetary dust is very tenuous near the sun and relatively denser at greater distances. A solar probe at 0.3 A.U. would see an F-corona with an intensity reduced by at least a factor of 3.3 and possibly by over a factor of 10. A reduction by a factor of 3.3 in the brightness of the F-corona would make it comparable with the brightness of the K-corona (at the times and position indicated) at about two radii above the solar limb, and a reduction in the F-corona brightness by a factor of 10 would make the two comparable in brightness at distances varying from 3-10 radii above the solar limb. Direct observations of the corona at 0.3 A.U. will therefore show much more of the structural detail of the true K-corona than will observations at 1 A.U.

Interpretation of available coronal data in terms of the spatial and thermodynamic properties of the corona depends quite heavily on our ability to separate accurately the F and K components of the corona. Observations could be made in white light and would require either imaging or scanning of the corona.

E - 3-D Corona.

One of the major unsolved problems of the solar atmosphere is the nature of the spatial irregularities in density and temperature. The structure is complex, and the proper interpretation of spectroscopic data depends quite critically on the precision with which the geometry can be specified. The effective path length through which emergent coronal radiation originates is long compared to many individual features in the corona. As a result, many of these features are obscurred by chance superposition and over-lapping with other features.

The great distance of the sun from Earth makes interpretation of the spatial configuration of any observed coronal structures difficult. For example, it is not known whether the long equatorial streamers of the corona at sunspot minimum form a continuous disk encircling the sun or whether they are descrete features like spokes radiating from a central hub.

If we assume that a given streamer is a spoke-like structure we cannot tell where it is anchored in relation to features on the solar disk without forming a three dimensional coronal picture.

Simultaneous pictures of the corona made from two points which subtend an angle of about 10° or greater when viewed from the sun could be used to construct three dimensional models of the corona that are considerably superior to models currently available. The success of such a program depends substantially on the spatial resolution of the pictures and on the angular separation of the observing points.

One picture of a pair, of course, could be obtained from a white light coronagraph aboard an orbiting Earth satellite or from the ground at a total solar eclipse. A similar instrument aboard a space probe could provide a good second picture. Since the primary requirement is to get adequate angular separation of the two observing points there is no particular reason for a close approach to the sun.

F - Zodiacal Light and F-Corona. (Suggested by Newkirk)

From the intensity and polarization of the zodiacal light and the variation of these quantities with elongation angle from the sun it is possible, in principle, to determine the size distribution of particles in the interplanetary medium. The interpretation of such observations is greatly complicated by the fact that not only the size distribution but also the spatial distribution of the scattering particles must be inferred from the observations. With so many parameters required to describe the interplanetary dust it is not surprising that the observations lead to ambiguous results. Observations of the zodiacal light or the F-corona from a "Close-In Solar Observatory" as it slowly approached the sun would be of inestimable value since the parameters of the spatial distribution could be inferred directly from the observations.

Also by performing such an experiment we might well be able to answer the question of how large a sphere of particle free space the sun has carved out of the interplanetary medium. Several researchers have estimated that the solar system within the orbit of Venus is essentially free of interplanetary particles. Such measurements could not only answer the direct question of what is the distribution of interplanetary material in the inner solar system, but would also shed light on the rather intriguing problems of the dynamics of the interplanetary particles.

The instrumentation required to observe the intensity, the polarization, and the direction of polarization of the zodiacal light at representative angles covering nearly the entire sky would be extremely simple. Only the cone of approximately 20° half-angle centered on the sun would be excluded from measurement in order to keep the optical system of photometer to the simplest possible form. The sun shield of the satellite could be used as a rather large occulting disk to prevent direct photospheric light from striking any portion of the zodiacal light photometer, which would be on the anti-solar side of the vehicle. The exact program by which the zodiacal light photometer would scan the sky would, of course, depend upon the type of satellite stabilization.

The accuracy with which the observations would be required would be approximately one percent in relative intensity. To accomplish this stability most simply it would be necessary to calibrate the photometer on the attenuated radiation of the direct solar disk seen through the axis of the satellite.

We make the, admittedly inexperienced, guess that a zodiacal light photometer-polarimeter of approximately 2 or 3 inch aperture and its associated electronics would weigh approximately five to ten pounds. Assuming that the photometer were to examine the zodiacal light in 10° by 10° samples we find that approximately 500 sampling positions in the sky would be required. With 3 pieces of data to an accuracy of one percent from each sampling position we should need approximately 1.5×10^5 pieces of information while the satellite is in a given position in the solar system. Under the additional assumption that data is desired from at least ten different locations in the solar system from 1 A.U. to 0.3 A.U. approximately 2×10^6 pieces of information would be required during the entire operation of the experiment.

The slightly different form of zodiacal light photometry involved in observing the F-corona requires a more sophisticated piece of equipment but

G - White Light Detection of Plasma Clouds. (Suggested by Athay)

A plasma cloud ejected from the sun may contain enough electrons to give the cloud appreciable brightness in the visual spectrum arising from scattering of sunlight. At an angular distance of 10° from the sun, a plasma cloud in which the product of electron density, N_e, and cloud diameter, L, is 10^{15} cm^{-2} would have about the same brightness as the zodiacal light at the same elongation angle. This value of $N_e L$ is arrived at by extrapolation from the coronal brightness. At 0.5 radii beyond the solar limb, $(N_e L)$ corona $\approx 10^{17}$ cm^{-2}. At 10° from the limb the flux density of photospheric radiation is reduced by about 10^{-2} and a cloud with $N_e L \approx 10^{15}$ cm^{-2} could be about 10^{-4} as bright as the corona at 0.5 radii. This is comparable to the brightness of the zodiacal light.

A zodiacal light photometer scanning across the plane of the ecliptic near the sun would be capable of detecting such clouds. In this case there is not so much advantage in a close approach to the sun. On the other hand, a zodiacal light or F-corona photometer would almost automatically detect these clouds if properly programmed.

H - Rotation of Interplanetary Matter and Solar Wind. (Suggested by Billings)

The extent of the coupling between interplanetary material and the rotating solar corona is of prime importance in both solar and interplanetary physics. Near the sun the gas and magnetic field must rotate with the sun, essentially as a solid body. At some distance further out this solid body rotation will break down and the motion of the gas and magnetic field will be determined by other factors. The limit of solid body rotation may be different for the gas than it is for the magnetic field.

If there is no solar wind and no magnetic field, the solid body rotation of the gas should break down in the region where the kinetic energy of rotation equals the gravitational potential energy. If the wind is blowing in the absence of a general magnetic field, the solid body rotation of the gas will break down either when the expansion energy exceeds the potential energy or when the expansion velocity becomes supersonic. The presence of a magnetic field will significantly alter these approximate criteria for rotation of the gas if the magnetic field energy is comparable to either the kinetic energy or gravitational potential energy. This is not likely the case in the interplanetary medium. If we neglect both the solar magnetic field and the solar wind, the kinetic energy due to rotation is equal to the gravitational potential energy at about 0.2 A.U. Using Parker's[1] model of the solar wind, we find that the kinetic energy of expansion and gravitational potential energy are equal at about 0.1 A.U. and the wind becomes supersonic at about .025A.U. The latter two numbers are uncertain to a rather large extent. The rotational velocities at 0.1 A.U. and 0.2 A.U. are 44 and 88 km/sec, respectively.

Both the speed and gradient of the solar wind are very sensitive to the temperature structure of the corona. Hence, observations of the speeds and directions of motion of the solar wind particles could give valuable information on the thermal properties of the corona. It appears, however, that unless a probe approaches within about .05 A.U. of the sun relatively little information will be obtained in addition to that already obtainable at 1 A.U.

The co-rotation of the solar magnetic field depends substantially upon the nature of the solar wind as well as upon the solar and interstellar magnetic fields. Axford, Dessler and Gottlieb[2] have recently suggested that the solar magnetic field co-rotates with the sun out to about 50 A.U., whereas the gas co-rotation stops at about .05 A.U. If this is the case, then not too much is to be gained by mapping magnetic field vector between Earth and sun for solar quiet periods unless distances within about .05 A.U. of the sun are possible.

I - Solar Neutrons. (Suggested by Todd)

It is probable that the outer regions of the sun's atmosphere can produce energetic neutrons capable of escaping the gravitational field of the sun. At times of solar activity, protons with energies of a few Mev up to hundreds of Mev are observed to emanate from the sun. Such protons will almost certainly undergo interactions with nuclei, causing charge exchange scattering and producing fast neutrons. Other possible interactions are nuclear disintegrations and evaporations (star-formation). Star production in the solar corona then can lead to neutrons of at least 10 Mev energy. A mechanism such as this indicates a strong dependence of neutron production upon the eleven-year solar cycle. It should also be pointed out that neutrons produced at depths greater than 150 g/cm^2 will have a large probability of absorption within the sun.

Several attempts to measure solar neutrons have been made with negative or ambiguous results and it is clear that at a distance of one astronomical unit the number of such neutrons cannot be large compared to the number of neutrons in the earth's outer atmosphere arising from primary cosmic rays and from albedo processes.[3-8] However, in the experiments thus far accomplished, the neutrons produced in the atmosphere by cosmic rays and by albedo processes undoubtedly mask the presence of solar neutrons. It should further be pointed out that in the production processes mentioned above the neutron spectrum produced should be expected to be a power law spectrum with appreciable production only at energies lower than, say, a couple of hundred Mevs and probably with the production concentrated primarily at energies of a few tens of Mevs and less.

Production of neutrons in spacecraft, or albedo neutrons

A solar probe traveling to within 0.3 A.U. of the sun presents an unprecedented opportunity for an experiment designed to detect and monitor the solar neutron spectrum. Since the likelihood is that the neutron production is appreciable only at the lower energies, an enhancement in the counting rate obtained on such a satellite, in addition to the simple $1/R^2$ variation which would enhance the solar neutron counting rate by a factor of about 10, would be encountered due to the increased survival probability of the lower energy neutrons at 0.3 A.U. from the sun. The enhanced counting rate due to increased survival probability alone for a few selected energies for a satellite at 0.3 A.U. is shown in Table I. Additionally the background of neutrons in the outer atmospheres of the earth which have plagued earlier attempts to detect solar neutrons will be attenuated by an additional $1/R^2$ factor (amounting in this case to a decrease in the counting rate of telluric neutrons by a factor of about 10^8). Neutrons in interplanetary space which belong to the primary cosmic ray flux will probably be small in number and also of exceedingly high energy so that they will be of no importance as a background to the experiment to detect solar neutrons.

The energy spectrum of neutrons in the vicinity of the earth is one which decreases rapidly with increasing energy, so that by far the greatest number occur at energies much less than 1 Mev. Therefore, in addition to the attenuation of the background by the $1/R^2$ factor, there will be a further attenuation of telluric background by a decay of the neutrons, leading to a further decrease by at least a factor of the order of 10^4 for an energy of 1 Mev and 10^{13} for an energy of 0.1 Mev.

As a result of these various factors, an experiment to detect solar neutrons operating at a distance of 0.3 A.U. from the sun would experience a ratio of solar neutron count to background of the order of a factor of 10^{12} to 10^{30} times better than that experienced by previous experiments in balloons, rockets, and even low altitude satellites.

In spite of the increased signal to background advantage to be enjoyed by a neutron detector on a satellite approaching close to the sun, it would be desirable to make the detector directional and to arrange for it to point away from the sun at least once in a while in order to demonstrate definitely that neutrons are coming from the sun. The directionality required of the detector for this purpose is of a crude nature only and pointing could be correspondingly crude.

Table I

Neutron Survival Probability at 0.3 A.U. Relative to that at 1.0 A.U.
(T = 13 minutes)

Neutron Energy (Mev)	Relative Survival Probability
0.1	2.2×10^{13}
1.0	1.5×10^{4}
10	24.5
30	4.9
100	2.9
1000	1.6

J - U. V. and X-ray.

Ultraviolet and X-ray data for the sun are still seriously lacking in spatial resolution on the solar disk and in the detection of faint fluxes. Both of these problems could be substantially helped by a solar probe at 0.1 A.U. or closer. At the present, however, it seems more advantageous to concentrate on the perfection of detectors and image forming devices than to expend our energy in a close solar probe.

K - <u>Backside Solar Activity</u>.

From time to time it is suggested that activity on the opposite side of the sun can result in energetic solar particles observed at Earth. While such suggestions are not rare, they tend to become rarer, for a given phenomena, as more data are accumulated. Nevertheless, it would be of interest to monitor activity on the side of the sun opposite Earth. There does not seem to be any compelling reason for a close approach to the sun however.

L - Radar Sounding of Corona.

Study of the solar corona and solar activity by means of reflected radar signals holds promise of yielding significant new information that will aid in understanding these phenomena. Power requirements for the transmitter decrease markedly, and, to some extent, the information content of the reflected signal increases, as the distance from the transmitter to the sun is decreased. Power requirements, however, seem to make this experiment prohibitive at present. For this reason, we have not discussed this question in detail.

M - Faraday Rotation and Doppler Shift. (Suggested by Billings and Little)

The reception of a radio signal of known initial polarization from a transmitter on a solar probe would yield information on the magnetic field and electron density of the intervening medium. The Doppler shift of the signal, produced by phase shifts in local irregularities, in a similar manner would indicate the extent of motions along the path of the signal. In effect one would measure the integral of the magnetic field, density distribution, or ordered motions over the path of the signal. Superimposed upon this would be intrinsic time variation in these parameters. In fact, the local time variation may be short compared to the progress of the probe in orbit. At best it is likely to be a difficult experiment to interpret. One further difficulty in the measurement of the Faraday rotation is introduced by the unknown contribution to the polarization of the signal in transversing the ionsophere. It is well established that there are frequent local variations of short periods in the ionosphere which alter the polarization. Thus, a probe experiment designed to measure Faraday rotation in interplanetary space would require simultaneous measurements of Faraday rotation in the ionosphere along the same ray trajectory.

N - Excitation of Plasma Oscillation. (Suggested by Little)

The electron density in the vicinity of a probe presumably could be determined by the excitation of local plasma oscillations. A swept low frequency radio signal transmitted from the probe would produce oscillations of the electrons irradiated by the signal. At the local plasma frequency a resonant oscillation would occur and could be detected by suitable circuitry. This technique provides a relatively simple means of determining electron densities in the vicinity of the probe, but not so close as to be influenced by the vehicle itself.

O - Solar VLF Emission.

The possible existence of VLF emission in the solar atmosphere is of importance in solar physics and offers a possible additional means of studying the solar atmosphere. A close solar probe, for example, might detect "whistler" type phenomena in the form of VLF emission trapped in the sun's general magnetic field. This and other phenomena associated with VLF emission would give valuable information on the over-all structure of the solar atmosphere and the solar magnetic field.

P - Radio Spectrum Gradient. (Suggested by Lund)

The purpose of this experiment is to provide clues to the emission mechanism(s) for radio emission in the solar corona. This information is necessary in order to be able to write correct source functions for the radiative transfer problem.

The known emission mechanisms produce radically different spectral "signatures." These spectra may be distinguished by the slope of the spectral power density with frequency. It is proposed to sample these slopes at a number of discrete low frequencies down to the plasma frequency corresponding to known electron densities in the region between sun and earth.

Directional information is necessary to isolate any observed emission as being of solar origin. Since the frequency consideration introduced above requires antenna structures which are small compared to the wavelength, directional information must be derived from antenna response minima, rather than maxima. Improvement of the signal-to-noise ratio by placing the experiment close to the sun is clearly desirable.

Q - Fields and Particles.

While we have not given detailed consideration to the many fields and particles experiments that are suggested by a close solar probe, we submit the following general remarks. Solar events resulting in an ejection of plasma clouds with embedded magnetic fields that penetrate at least as far as the orbit of Earth are not infrequent. It seems very probable that at distances from the sun of the order of 0.3 - 0.1 A.U. such plasma-magnetic field events will be considerably more frequent than at 1 A.U.

The solar mechanism leading to the expulsion of energetic particles and photons is not understood. Part of the difficulty in attempting to interpret available data in terms of physical mechanism is that events that are otherwise very similar sometimes produce energetic particles and sometimes do not. This forces us to conclude that we have not yet discovered a really satisfactory link between the production of particles of either high or low energy and other specific characteristics of related solar events. Many specific optical and radio characteristics of flares have been proposed as being closely related to polar proton events. It must be admitted, however, that none of these proposed relationships purport to answer the basic question of just how the energetic particles are accelerated and what specific relationship the acceleration mechanism has to the production of the related optical or radio event. These questions must be answered, but they cannot be until we know much more concerning the total flare event, both in the electromagnetic and particle spectrum.

R - Gravitational Red Shift. (Suggested by Bender)

A further experiment to be considered for a low perigee solar satellite is a measurement of the slowing down of light going by the sun. One version of the experiment would be to put a frequency standard and a pulsed low threshold laser aboard the satellite. With a 10^{-4} radian beam aimed at the earth and a 0.1 joule output this gives about 10^3 photons/meter^2 of collector in 10^{-7} sec and in less than a 1 Å bandwidth. This should be compared with fluctuations in scattered sunlight near the limb in a roughly 10^{-8} sterradian solid angle for a comparable time. Since the solar disk gives about 5×10^6 photons/meter^2, in 1 Å, 10^{-8} sterradians, and 10^{-7} sec, the fluctuations about 0.1 solar radius from the limb should be small. The laser would flash perhaps every few minutes at times controlled by the satellite frequency standards and the received pulses could be timed with respect to frequency standards on the earth to better than 10^{-7} sec. Since the experiment would take of the order of a day and a frequency standard uncertainty of one part in 10^{11} would give a 10^{-6} sec per day time uncertainty, the major uncertainties would probably be in the satellite frequency standard and in the knowledge of the satellite orbit.

For a satellite passing behind the sun, the predicted time delay due to light passing through the sun's gravitational field is given by the general theory of relativity (J. Weber, private communication) as

$$\Delta t = \frac{GM}{c^3} (\ell n\ r + R - 2\ell n\ D),$$

where r and R are the distances of the satellite and earth from the sun and D is distance of closest approach of the earth-satellite line to the center of the sun. The maximum rate of change of Δt occurs at the limb and is

$$\frac{d}{dt}(\Delta t) = -\frac{2GM}{c^3} \cdot \frac{1}{R_\odot}\frac{dD}{dt},$$

where $R_\odot$ is the solar radius. For a 0.3 A.U. perigee orbit, the result is about 10^{-5} sec per day on the first pass about 4 months after launch and about 2×10^{-5} sec per day on another pass about 9 months after launch.

Another version of the experiment would be to have a transponder aboard the satellite and measure the time directly. However, 10^{-7} sec timing over more than 1 A.U. using conventional microwave communications systems seems difficult. Whether a laser transponder would be simpler than a frequency standard aboard is hard to guess.

The importance of a fairly small perigee comes from the resulting faster passage behind the sun and thus lower stability requirements on the frequency standard. Also, if the perigee is near the orbit of Venus or further out it will take two years or more for the vehicle to make its first pass behind the sun. Two easy-to-analyze orbits are those with periods 1.5 and 2.5 times shorter than the earth's. These put the satellite at perigee one year after launch at solar distances of 0.53 and 0.09 A.U. and give rates of change for the time delay of about 25 microsec/day and 150 microsec/day. The 0.53 A.U. perigee orbit would not be quite as suitable for the experiment as a closer orbit because of the smaller number of passes per year but would be usable. If orbit uncertainties are small enough the predicted change in delay could be checked to 5% or better.

Particles and field observations near the sun at the times of solar flares hold promise of increasing greatly our knowledge of the flare phenomenon. No one can predict with certainty just how much we stand to gain by such observations, but certainly this is a promising space experiment with great potential reward.

For these experiments, an approach to about 0.3 A.U. from the sun would be very valuable. An approach to 0.1 A.U. would be considerably more valuable, however, S - Interstellar Wind. (Suggested by Warwick)

The sun's peculiar motion relative to the nearby stars, and presumably relative to the galactic framework, has a magnitude of about 20 km/sec. Thus, interstellar gas, mostly neutral hydrogen, will sweep past the sun in hyperbolic orbits corresponding to a velocity at infinity of 20 km/sec. Some of the hydrogen atoms will be ionized by the sun's radiation and will be captured by the solar and interplanetary fields. The average density of the gas, at infinity, is of the order of 1 hydrogen atom per cm^3. Both the concentration and velocity of the gas will increase near the sun, however.

It is estimated (see next section) that at .05 A.U. the interstellar density of neutral hydrogen gas may be as high as $10^2 - 10^4$ cm^{-3} and that the optical thickness in the interplanetary region might easily exceed 0.1. If so, the interstellar wind should be detectable through a careful study of the Lyman-alpha central absorption core or through a study of the scattering of Lyman-alpha by interplanetary hydrogen. At a perihelion distance of 0.3 A.U. a neutral hydrogen atom in the interstellar wind would have a velocity of about 80 km per sec. This could produce a Doppler shift in the Lyman-alpha line observed in the direction of motion of 0.32 A.

IV - Condensed Summary of Experiments and Evaluation

The following table contains a rough classification for each of the foregoing suggestions in terms of their scientific merit. We also include an indication of the desirable maximum distance from the sun, and a general indication of required pointing. In making the classification and indicating maximum distances, we have paid little or no attention to either the difficulty of attaining a close approach or the difficulties involved in carrying out the suggested experiment given the necessary vehicle.

Suggested Experiment	Scientific Merit	Maximum Sun-Probe Distance	Pointing and Direction	Scan
A - Lyman-α absorption	I	.5	sun ± 5°	none
B - Lyman-α emission	I	.5	90°	180° altitude sweep
C - Lyman-α corona	I	1	sun ± ½°	none
D - F and K corona	II	.3	sun ± ½°	none
E - 3-D corona	II	1	sun ± ½°	none
F - Zodiacal light	I	.3	within 10° of sun	sweep alt. & az.
G - White light plasma clouds	II	1	same as F	
H - Rotation & solar wind	I	.05	none	
I - Neutrons	I	.3	sun ± 10°	none
J - U.V. & x-ray	II	.1	sun ± ½°	none
K - Backside activity	III	1	none	
L - Radar sounding	III	.1	----	
M - Faraday & Doppler	III	.3	----	
N - Plasma oscillation	II	.3	----	
O - Solar VLF	II	.1	----	
P - Radio spectrum gradient	II	1	----	
Q - Fields & particles	I	.3	----	
R - Gravitational ~~Red Shift~~ deflection of Laser beam	II	.3	----	
S - Interstellar wind	III	1	----	

V - Added Notes on Suggested Experiments

A - The Absorption Core of Solar Lyman-alpha Produced in a Neutral Component of Interplanetary Hydrogen Gas.

Some of the physical properties of the interplanetary gas follow fairly directly from general geophysical and astrophysical circumstances. For example, the range in density values lies between 1 cm^{-3} and 10^3 cm^{-3} proton-electron pairs. The former value is the over-all density of matter in interstellar space, and the latter, the Chapman value from magnetic storm data. A plausible density of neutral plus ionized gas is then, say, 10^2 cm^{-3} at the earth's distance from the sun. If the gas originates at the sun, with a velocity exceeding the escape velocity (e.g. the solar wind), and moves at substantially constant speed v at the earth's orbit, say at 1000 km/sec, then the flux of atoms at distance r is $nv\ 4\pi r^2 + Q$, a constant where n is number density. Taking n = 250 and $v = 10^3$ $km \cdot sec^{-1}$ at 1 A.U., $Q = 6 \times 10^{37}$ sec^{-1}, or 10^{14} $grams \cdot sec^{-1}$.

With this simple model of the interplanetary gas, we can formulate the problem of the absorption, by the neutral component of the gas, of central regions of the chromospheric Lyman-alpha line. The optical depth τ_o, at line center of the interplanetary line, is

$$\tau_o = \int_{R_\odot}^{r} n_1\, \alpha_o\, dr$$

If the gas flows at an average velocity of 500 $km \cdot sec^{-1}$, the Lyman-alpha line absorption (or emission) will be shifted 2 Å to the blue of the chromospheric line. Since the chromospheric line is only about 1 Å wide we could observe the gas perhaps most easily by observing the interplanetary emission in the Lyman-alpha line.

On the other hand, if we assume that the density is constant (at say $n = 10^2$), and the gas is stationary, we can find the way in which reversal of Lyman-alpha would build up in the planetary system as one observes the sun from different distances. For example, this static model would indicate the possible role of interstellar gas, incident as neutral atoms onto the solar system, in determining the density of the interplanetary medium.

The absorption rate of Lyman-continuum photons by a neutral hydrogen atom moving with velocities less than about 10^4 km/sec with respect to the sun is given by $\alpha_\nu P_c$ where α_ν is the absorption coefficient in the Lyman-continuum and P_c is the Lyman-continuum photon flux. Over the first 100 Å of the Lyman continuum, $\overline{\alpha}_\nu \approx 5 \times 10^{-18}$ cm^2 and $P_c \approx 6 \times 10^9$ cm^{-2} sec^{-1} at the orbit of the earth. Thus, the absorption rate is 3×10^{-8} sec^{-1}.

The collisional ionization rate for a neutral hydrogen atom depends upon electron density and temperature. For an electron density of 10^2 the collison rates are:

temperature	2×10^4	5×10^4	1×10^5
collisional ionization rate sec^{-1}	7×10^{-10}	1×10^{-7}	2×10^{-5}

Near the orbit of earth we expect $\tau \leq 5 \times 10^4$ and $N_e \approx 10^2$, so that photoelectric ionizations predominate somewhat over collisonal II ionizations.

As we approach the sun, electron density, temperature and Lyman-continuum flux density all increase. The Lyman-continuum flux density increases in proportion to r^{-2}, and electron density obeys essentially the same law[1] up to about 0.1 A.U. Within 0.1 A.U. the electron density increases faster than r^{-2} and collisons will predominate due to this effect alone. Also, the increase in temperature nearer the sun will greatly increase the collisional ionization rate.

At 0.3 A.U., the temperature may be as high as $.5\text{-}1 \times 10^5$°K, in which case collisional ionization rates probably exceed photoionization rates by factors of about $10\text{-}10^3$ respectively.

A neutral hydrogen atom in the interplanetary system at a distance between .5 - 1 A.U. will have a lifetime for ionization of about $.8 - 3 \times 10^7$ sec, or about 3 - 12 months, respectively. If it is moving at a speed of, say, 20 km per sec, it will travel a distance 1 - 4 A.U. during this time. Fast moving atoms with perigee distance > .5 A.U., therefore, will have a low probability for ionization by solar radiation.

The ratio of neutral, N_H, to ionized, N_p, hydrogen atoms is given by

$$\frac{N_H}{N_p} = \frac{\text{recombination rate}}{\text{ionization rate}} .$$

The recombination rate is $5 \times 10^{-13}\ N_e\ \text{sec}^{-1}$ at 10^4°K and $8 \times 10^{-14}\ N_e\ \text{sec}^{-1}$ at 10^5°K. Near 1 A.U., then, we expect $N_e \approx 10^2$ and a recombination rate of about 5×10^{-11} $\sec^{-1}$. Thus, $N_H/N_p \approx (5 \times 10^{-11}/3 \times 10^{-8}) \approx 10^{-3}$ and $N_H \approx 0.1$. At 0.3 A.U., the recombination rate is about 8×10^{-11} $\sec^{-1}$ and the collisional ionization rate about $2 \times 10^{-6} - 2 \times 10^{-4}$. Thus, $N_H/N_p \approx 4 \times 10^{-5} - 4 \times 10^{-7}$ and $N_H \approx 4 \times 10^{-2} - 4 \times 10^{-4}$.

The foregoing calculations assume that a given hydrogen atom remains in the local environment sufficiently long to reach ionization equilibrium. Brandt[9] has shown that this is probably not strictly the case and that diffusion transport may be important in the equilibrium. This may be considered as an additional uncertainty in the calculations, but this added uncertainty is not likely to change the order of magnitude of the predicted values of N_H.

We now consider the problem of interstellar gas flowing past the sun. If this gas is ionized by the sun's u.v. flux, it then becomes subject to the magnetic fields of interplanetary space and is in effect captured by the solar system. The density of captured gas created in this process may be estimated as follows:

The neutral hydrogen of the interstellar gas moves in a hyperbolic orbit around the sun, with a relative velocity at infinity that can be estimated to be 20 $\mathrm{km \cdot sec^{-1}}$. The minimum distance an atom of the gas would come to the sun if the above were not ionized en route is $r_o = D^2V^2/[G M_\odot + \sqrt{G^2M^2 + D^2V^4}]$ where D is the impact parameter of the atom. In a rough sense, the probability of ionization can be computed from the time $\underline{t}$ the atom spends at r_o from the sun, $t = \pi r_o/V_{peri}$ where V_{peri} is the speed of the atom at perihelion distance. $t = \pi r_o/(DV/r_o) = \pi r_o^2/DV$. The ionizations per atom at distance r from the sun per second are:

$$I = \int_{\substack{\text{solid}\\ \text{angle}}} \int_{\nu_o}^{\infty} I_\nu \mathcal{H}_\nu \frac{d\nu}{h\nu}\ d = 2\pi\ \frac{R_\odot^2}{r^2}\ \frac{\mathcal{H}_o \nu_o^2}{c^2}\ \frac{kT_r}{h}\ e^{-h\nu_o/kT_r}$$

where I_ν is the specific intensity, and T_r is the radiation temperature characterizing the solar Lyman continuum. The total number of ionizations for an atom initially moving with parameter D is

$$t = \frac{2\pi^2}{VD} R^2 \frac{\mathcal{H}_o \nu_o^2}{c^2}\ \frac{kT_r}{h}\ e^{-h\nu_o/kT_r}$$

and for this to be a 50 percent probability,

$$\frac{1}{2} = \frac{2\pi^2}{VD_{1/2}} R^2 \frac{\mathcal{H}_o \nu_o^2}{c^2}\ \frac{kT_r}{h}\ e^{-h\nu_o/kT_r}$$

which shows that $D_{1/2}$, the impact parameter within which over 1/2 the incident interstellar atoms are ionized, depends only on the sun, and the speed of the interstellar gas. If we set $V = 20\ \mathrm{km \cdot sec^{-1}}$, and choose T_r corresponding to a Lyman continuum photon flux of 6×10^9 photon $\mathrm{cm^{-2}\ sec^{-1}}$ at earth,

$$D_{1/2} = 0.3\ \text{A.U.}$$

Note that this computation ignores collisional ionization which is important at this distance. Thus, $D_{1/2}$ should be moved somewhat further out, say, $D_{1/2} = 0.5$ A.U.

The density of captured particles follows from an estimate of the rate of capture in comparison with the rate of loss. If N_{cor} is their density, V_{Ther} their thermal speed, and R_{cor} the radius of the corona within which the material accumulates, we equate

$$N_{cor} V_{ther}\, 4\pi R_{cor}^{\;2} = N_{INT}\, V\, \pi\, D_{1/2}^2$$

We used $D_{1/2}$ because the minimum distance of approach of an atom with impact parameters $D_{1/2}$ is about 10 $R_{\odot}$ ($= \frac{1}{20}\, r_{\oplus}$). Since $V_{ther} \sim V$, and $R_{cor} \sim \frac{1}{10}\, D_{1/2} \sim \frac{1}{10}\, D_{1/2}$

$$N_{cor} \sim 10^2\, N_{INT}$$

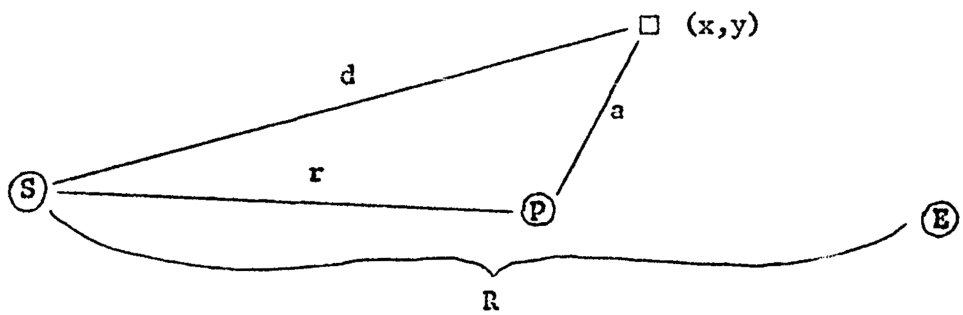
$N_{INT} \sim 1\ cm^{-3}$, averaged over large volumes of the Milky Way. In limited regions, N_{INT} may go as high as $10^2\ cm^{-3}$. Then

$$N_{cor} \sim 10^2 - 10^4\ cm^{-3}$$

over a sphere of radius 1/20 A.U. In order for the neutral hydrogen to be observed as an absorption feature, we should have $\tau_\alpha \approx 1$. If the density of the interstellar component falls as $1/r^2$ from 1/20 A.U. out to 1 A.U., then at Earth $n_{\oplus} \sim \frac{1}{400} \times 10^2 = \frac{1}{4}$; then $\tau_\alpha \sim \frac{3940}{[10^4/(1/16)]}$ (at $r_{\oplus}$) or $\tau_\alpha = 0.4\,[10 - \frac{r}{r_{\oplus}}^{-1}]$. An effect of this magnitude may therefore be observable, and suggests the desirability of a study of the variations of the Lyman-alpha core with distance from the sun.

B - Lyman-alpha Scattering by Interplanetary Hydrogen.

Lyman-alpha emission scattered by interplanetary hydrogen is illustrated by the following geometry:



If the photon flux density from the sun is $\ell_\odot$, the flux scattered into a 1 cm^2 aperture at the probe by a volume $2\pi a^2 \sin\alpha \, d\alpha \, da$ is

$$2\pi a^2 \sin\alpha \, d\alpha \, da \, N_H \frac{\cos\alpha}{4\pi a^2} \int \alpha_\nu \, \ell_\odot \, d\nu,$$

where α is the angle between the direction to the scattering volume and the normal to the aperture and N_H is the density of neutral hydrogen. For the case under consideration, we may assume that $\ell_\odot$ is uniformly distributed over a bandwidth of 1 Å, which is wide compared to the effective width of α_ν. We further assume that α_ν is Gaussian and obtain

$$\int \alpha_\nu \, \ell_\odot \, d\nu = \sqrt{\pi} \, \Delta \nu_o \, \alpha_o \, \ell_\odot = \sqrt{\pi} \, \Delta \lambda_D \frac{\lambda^2}{c} \alpha_o \, \ell_\odot = 5 \times 10^{-15} \, \ell_\odot$$

The solar photon flux $\ell_\odot$ may be written

$$\ell_\odot = L_\oplus \frac{R}{d}^{\,2}$$

where $L_\oplus = 2.7 \times 10^{11}$ cm^{-2} sec^{-1} is the flux density at the orbit of Earth.

Thus, the total scattered flux, L_p, passing through the 1 cm^2 aperture at p is

$$L_p = 1.4 \times 10^{-3} R^2 \int_0^\infty \int_0^{\pi/2} N_H \frac{\sin\alpha \cos\alpha}{2 d^2} \, d\alpha \, da$$

$$= 3.5 \times 10^{-4} R^2 \int_0^\infty \frac{N_H}{d^2} \, da$$

At 90° to the probe-sun line, $d^2 = r^2 + a^2$ in a direction opposite the sun $d = N + a$ and in the direction of the sun $d = r - a$. If we take N_H = constant, we obtain

$$L_p(90°) = 5.5 \times 10^{-4} N_H \frac{R^2}{r} = 8.3 \times 10^9 N_H \frac{R}{r},$$

$$L_p(180°) = 3.5 \times 10^{-4} N_H \frac{R^2}{r} = 5.3 \times 10^9 N_H \frac{R}{r},$$

and

$$L_p(0°) = 8 \times 10^{-4} N_H \frac{R^2}{r} = 1.2 \times 10^{10} N_H \frac{R}{r}.$$

The latter case $L_p(0°)$ assumes that $N_H = 0$ inside 0.3 A.U.

If we take $N_H \propto d^{-1}$, we obtain

$$L_p(90°) = 5.3 \times 10^9 N_H^\rho \frac{R}{r},$$

$$L_p(180°) = 2.7 \times 10^9 N_H^\rho \frac{R}{r},$$

and

$$L_p(0°) = 2.65 \times 10^{10} N_H^\rho \frac{R}{r}.$$

where N_H^ρ is the ambient density near the probe. Again $L_p(0°)$ assumes $N_H = 0$ inside 0.3 A.U.

C - Coronal Electron Scattering of Lyman-alpha.

A cubic centimeter of the lower corona "sees" a Lyman-alpha photon flux of about $2\pi\ (R/R_\odot)^2\ L_E \approx 7.5 \times 10^{16}\ cm^{-2}\ sec^{-1}$, where L_E is the photon flux per cm^2 and per sec at Earth. The Thompson scattering cross-section is $6.6 \times 10^{-25}\ cm^2$ and the coronal electron density is about 3×10^8 Thus, the photon flux scattered by 1 cm^3 is about 15 per sec.

The effective path length for a tangential ray through the inner corona is approximately $(2\pi R_\odot H)^{1/2} \approx 6 \times 10^{10}$, where H is the vertical scale height. Hence a 1 cm^2 tangential column scatters about 10^{12} photons per sec. Of these scattered photons, a fraction 3.6×10^{-28}, or 3.6×10^{-16} photons per sec, will pass through a 1 cm^2 aperture at the orbit of Earth. The flux of scattered Lyman-alpha photons from the entire corona at the orbit of Earth is $1.4 \times 10^6\ cm^{-2}\ sec^{-1}$. The flux at 0.1 A.U. is 1.4×10^8 $cm^{-2}\ sec^{-1}$.

The coronal scattered Lyman-alpha flux must be compared with the interplanetary scattering from the same solid angle. The solid angle subtended by the corona out to $2R_\odot$ is 3×10^{-4} sterradians and the preceding expressions for $L_p(0°)$ must be corrected by a factor 1.2×10^{-3}. Thus, at 1 A.U. we obtain

$$L_p(0°) = 1.4 \times 10^7\ N_H$$

for N_H = const and

$$L_p(0°) = 3.1 \times 10^7\ N_H$$

for $N_H \propto d^{-1}$ for $d \geq 0.3$ A.U. and $N_H = 0$ $d < 0.3$ A.U. If $N_H \gtrsim 0.1$, the interplanetary scattering from the direction of the sun would be comparable to the coronal scattering observed at 1 A.U. At 0.3 A.U. the coronal scattering would increase by a factor 10 and the interplanetary scattering would presumably disappear.

The mean Doppler velocity of coronal electrons (assuming 10^6°K) is 5500 km/sec, and the Doppler width of the scattered Lyman-alpha line will be about 22 Å. A spectrograph with 5 Å resolution would give reliable information on the line profile and would permit a determination of the electron temperature.

The profits of the interplanetary scattered Lyman-alpha will presumably have a Doppler width of about 0.04 - 0.13 Å due to thermal broadening at a temperature of 10^4 - 10^5°K.

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